

turning knowledge into practice

Fourth Annual Conference on Carbon Capture & Sequestration

Dry Regenerable Carbonate Sorbents for Capture of Carbon Dioxide from Flue Gas

Thomas O. Nelson, David A. Green, Raghubir P. Gupta, Jeffrey W. Portzer,
David Coker, William J. McMichael, and José Figueroa



RTI International is a trade name of Research Triangle Institute

3040 Cornwallis Road
Phone 919-541-8023

■ P.O. Box 12194

■ Research Triangle Park, North Carolina, USA 27709
Fax 919-541-8000

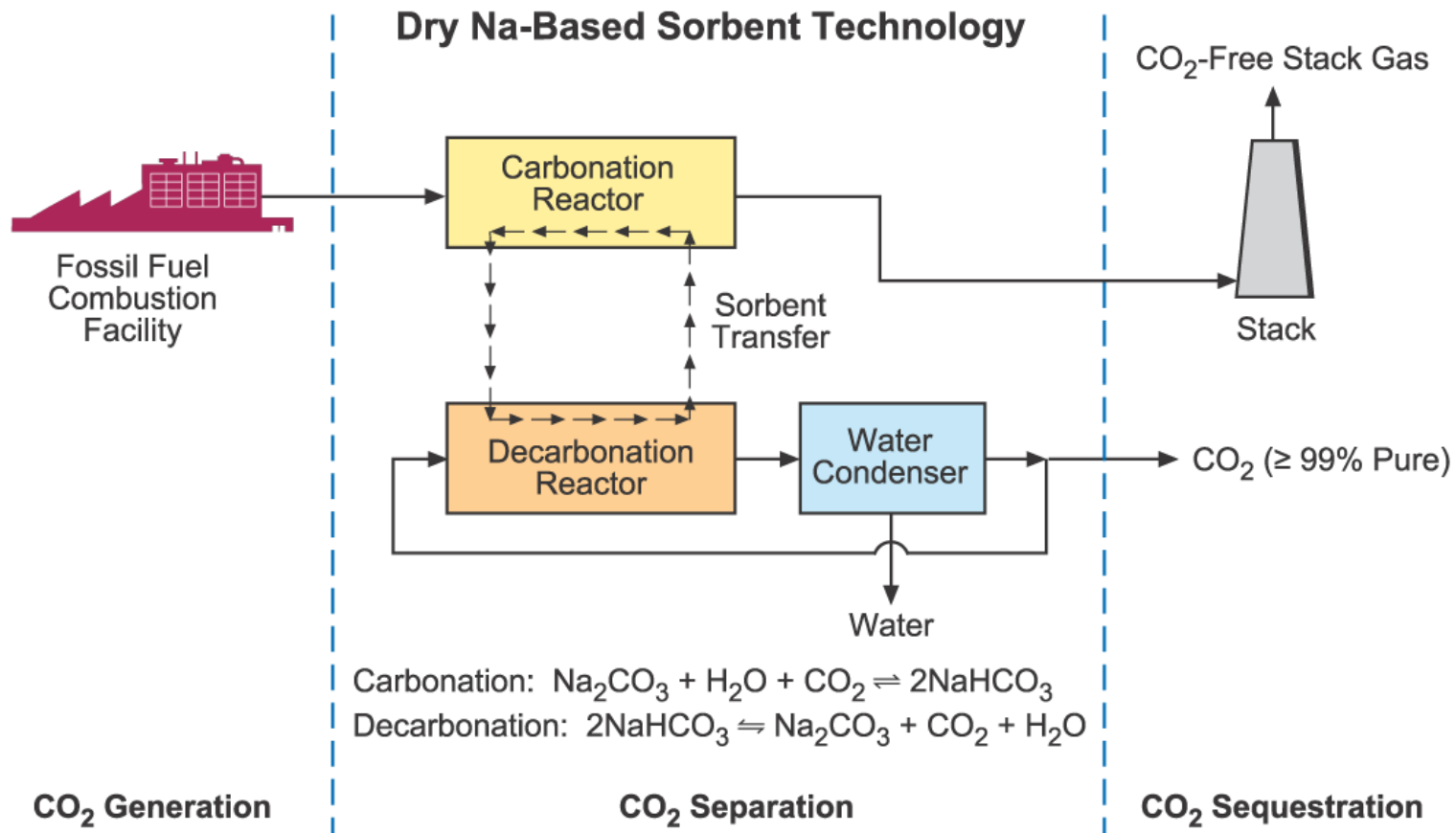
e-mail gupta@rti.org

Objectives

To develop a carbon dioxide separation technology that is

- Regenerable sorbent-based
- Applicable to both coal and natural gas-based power plants
- Applicable as a retrofit to existing plants, as well as to new power plants
- Compatible with the operating conditions in current power plant configurations
- Results in less than 10% increase in cost of electricity

Concept of the “Dry Carbonate” Process for CO₂ Capture from Flue Gas

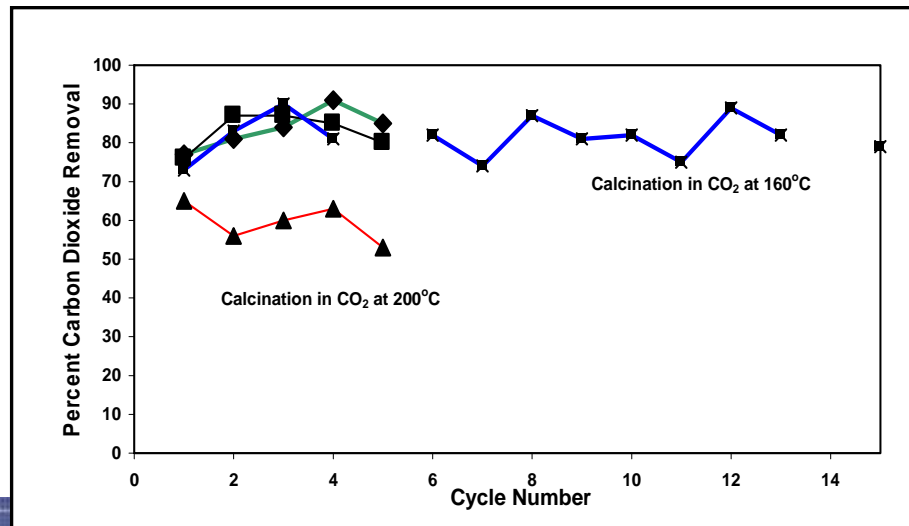


Previous Research

- Thermogravimetric analysis
 - Concept proven
 - Optimal absorption temperature: 60 – 80°C
 - Optimal regeneration temperature: > 120°C
 - Temperature sensitive kinetics – reaction favored at lower temperatures
 - SO₂ (0.1% to 0.4% in feed) produces decrease in CO₂ removal capacity
 - Able to regenerate in pure CO₂
- Fixed-bed studies
- Fluidized-bed studies
- Materials tested:
 - Calcined sodium bicarbonate (SBC) - NaHCO₃
 - Calcined trona - Na₂CO₃•NaHCO₃•2H₂O
 - Calcined potassium bicarbonate – KHCO₃
 - Supported carbonate sorbents

Highlights of Fixed and Fluid-Bed Studies

- 90% CO₂ capture was achieved.
- Regeneration temperatures above 120°C have little to no effect on the rate and extent of decarbonation reaction
- Rapid initial CO₂ removal rates
- Activity maintained for 15 cycles.
- Sorbent bed temperature rises during absorption and causes decline in removal rates



Why Develop Supported Sorbents?

- Fixed-bed operation is not feasible
 - Poor heat transfer: not ideal for self-extinguishing reaction (exothermic)
 - Endothermic sorbent regeneration is highly energy-intensive in a fixed-bed
 - Entrained-bed type reactor may be best choice
- Commercial carbonate materials may not work in entrained-bed
 - Harsh flow conditions result in severe attrition of commercial materials
 - Reactivity may not be adequate for short residence time of entrained-bed reactor
- Supported sorbents combine attrition resistance inherent to support material and reactivity of carbonate material

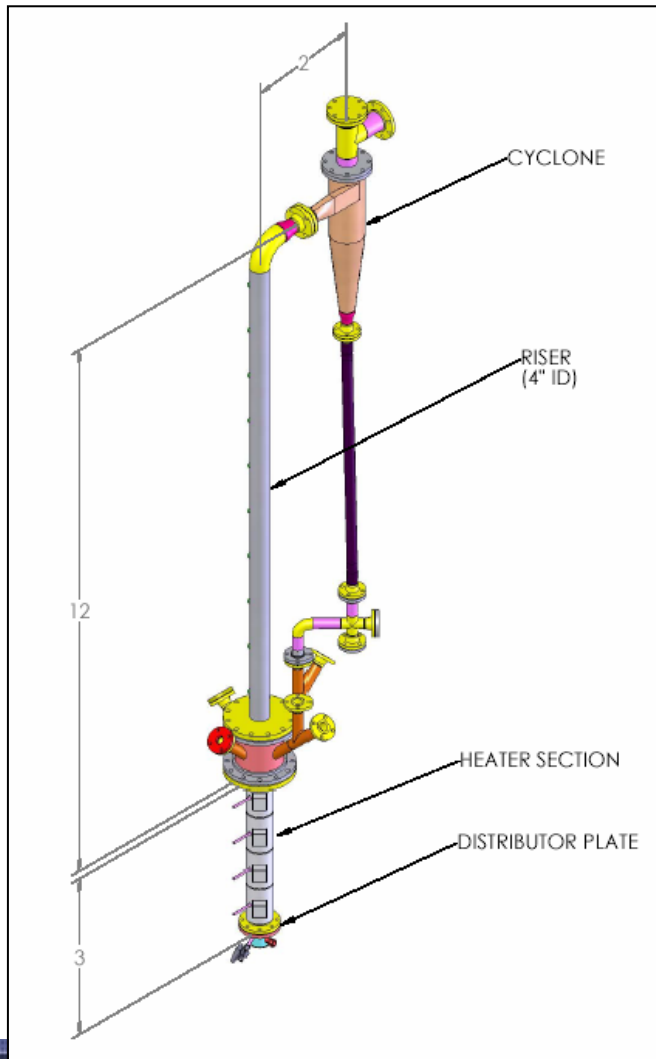
Supported Carbonate Sorbents

- Research project has produced over 70 experimental supported carbonate sorbents
- Optimized sorbent:
 - 15% Na₂CO₃ and 85% ceramic support
 - Bulk density: 0.96 g/cc
 - Avg. particle size: 76.4 microns
 - Surface area (BET): 96.5 m²/g
 - Attrition-resistance (AR¹): AR = 0.61
- 22 kg produced by commercial manufacturer (Süd-Chemie, Inc.)
- Produced for pilot-scale entrained-bed testing at CANMET in Ottawa, Ontario, Canada



$$^1\text{AR} = \text{Attrition Ratio} - \text{AR} = \frac{\text{Davison index (DI) of the sample}}{\text{Davison index (DI) of a standard}}$$

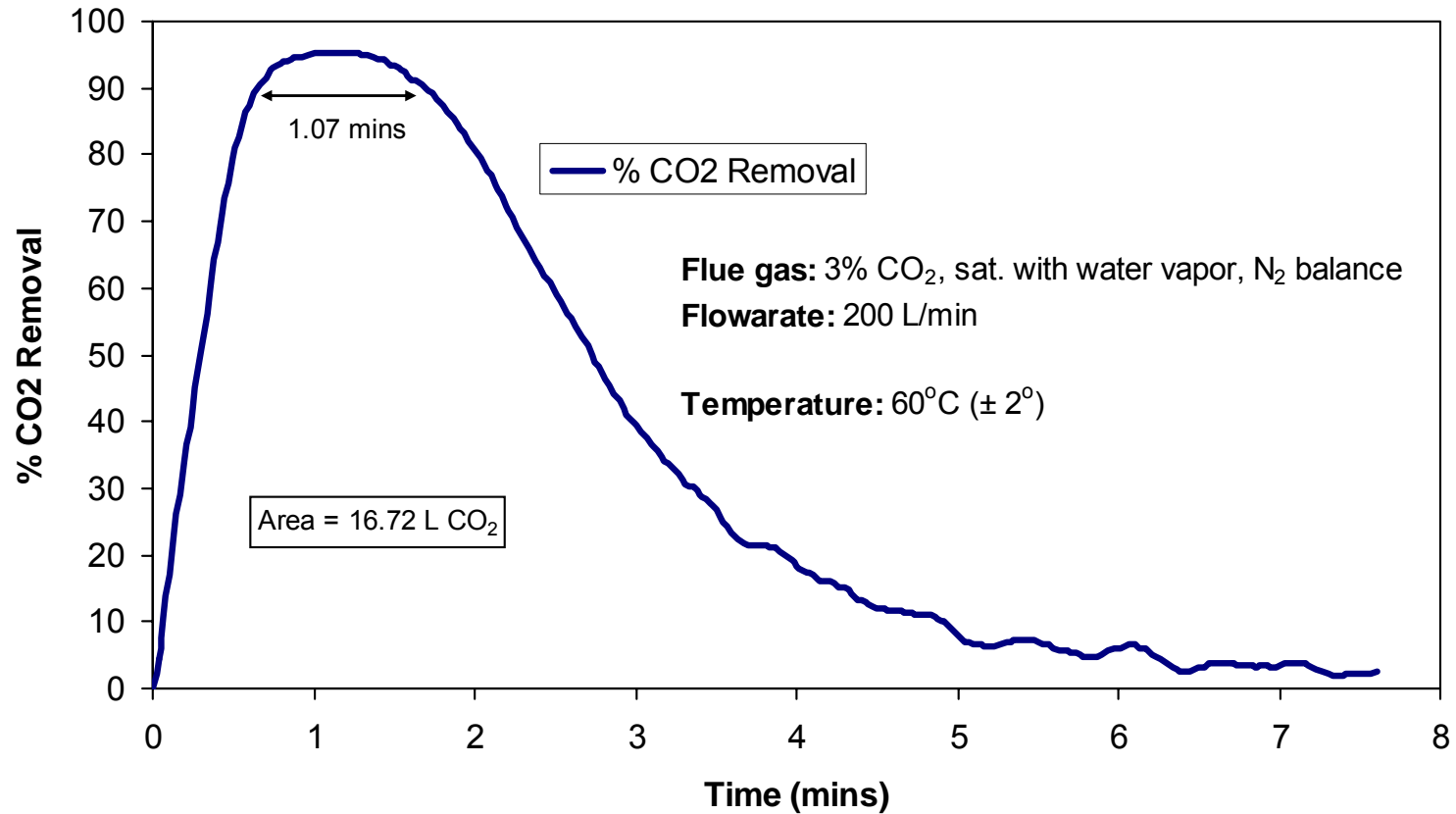
Entrained-Bed Testing at CANMET



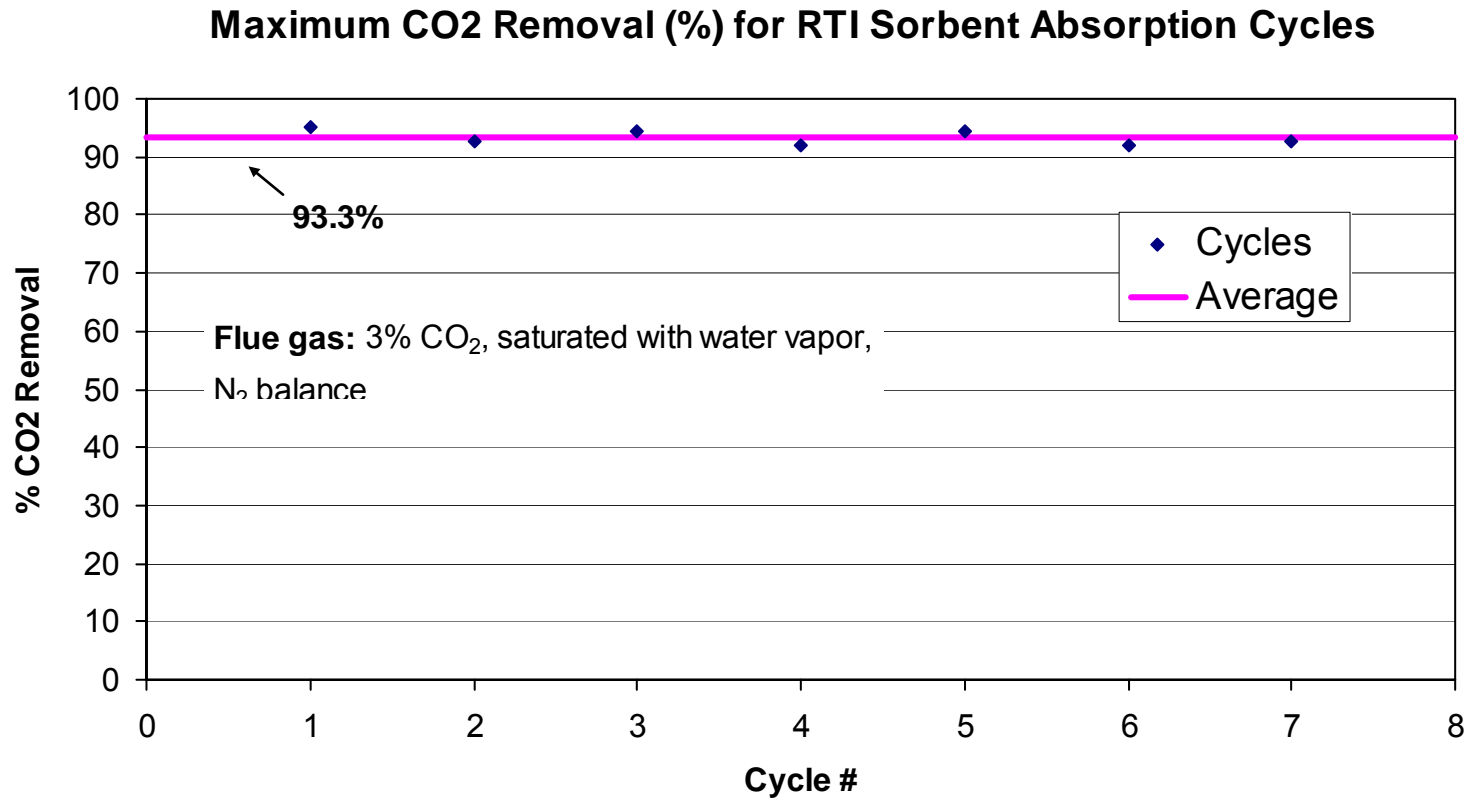
- Modified “Mini-CFBC” Circulating Fluid Bed Combustor
- 10 cm I.D. x 4 m high riser
- “Single Loop”
- Continuous circulation
 - Absorption mode (circulating)
 - Regeneration mode (bubbling)
- Gas analysis; data logging; sorbent sampling
- Sorbents: RTI supported sorbent, sodium bicarbonate and trona

RTI Sorbent: Absorption

RTI Sorbent: Cycle #1 Absorption - Percentage of CO₂ Removal



RTI Sorbent: Multi-Cycle CO₂ Removal



RTI Sorbent: Multi-cycle Tests

Absorption

<i>Cycle</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>	<i>7</i>
CO ₂ removed (L)	16.72	18.30	17.67	14.11	13.24	15.89	14.97
% CO ₂ removal (max)	95	93	94	93	92	92	92
Start temperature (°C)	61	60	56	60	64	61	65
Temperature rise (°C)	4	13	11	10	12	13	11

Regeneration

<i>Cycle</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>	<i>7</i>
CO ₂ released (L)	16.88	15.24	18.07	10.06	13.39	12.29	NA
Start temperature (°C)	187	166	189	186	141	150	NA
Average temperature (°C)	163	154	160	158	151	156	NA

RTI Sorbent: Multi-Cycle Attrition

Sorbent particle size after each entrained-bed cycle

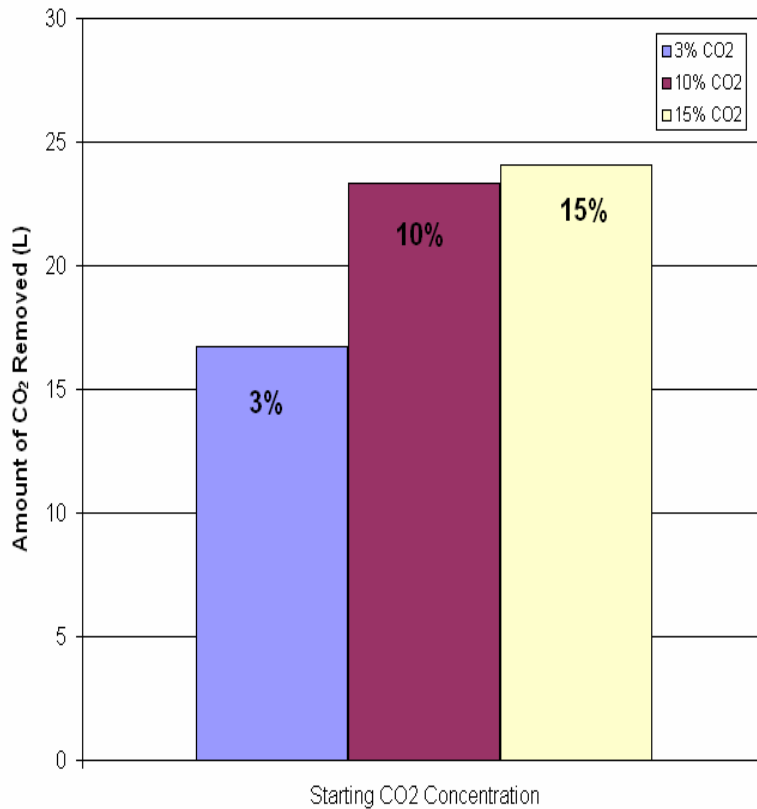
<i>Cycle</i>	<i>Fresh</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>
% of particles below 30 microns	2.7%	0.8%	0.9%	1.0%	1.2%	1.5%
% of particles below 50 microns	19.5%	16.1%	14.1%	20.6%	20.6%	21.4%
Average particle size (microns)	76.38	78.16	83.87	72.02	72.64	72.30

- Amount loaded (Cycle #1) = 5.40 kg
- Amount unloaded (Cycle #7) = 5.95 kg

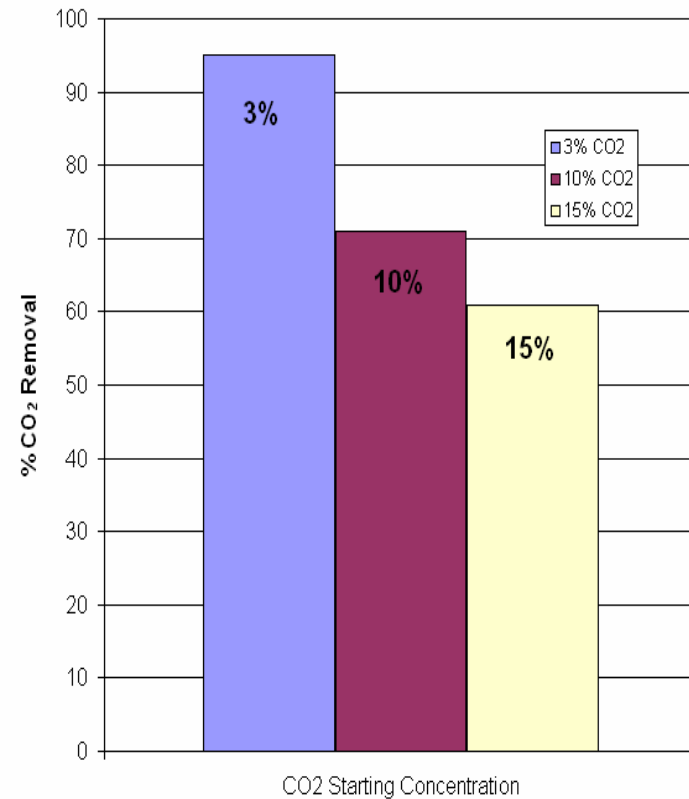
RTI Sorbent shows negligible attrition

Effect of CO₂ Starting Concentration

CO₂ Removed: Effect of CO₂ Starting Concentration

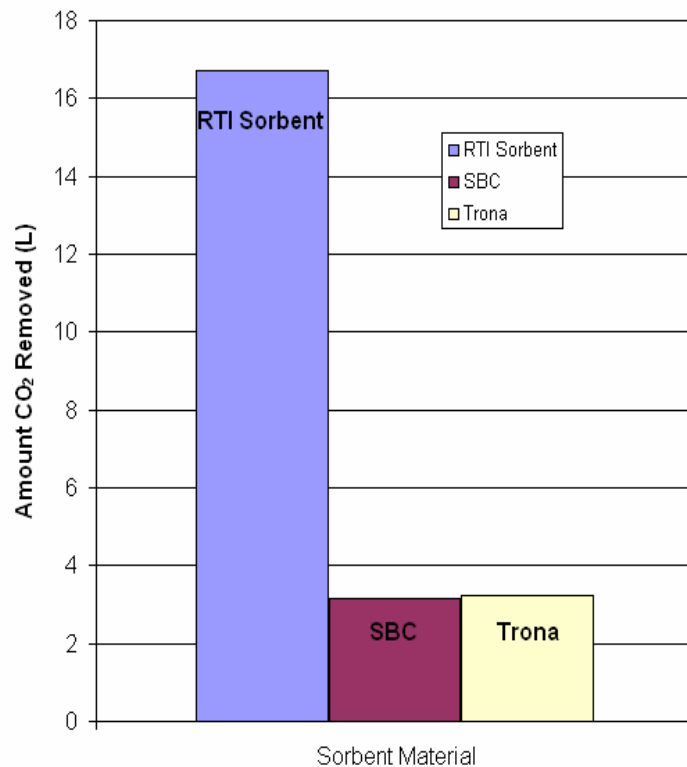


% CO₂ Removal: Effect of Starting CO₂ Concentration

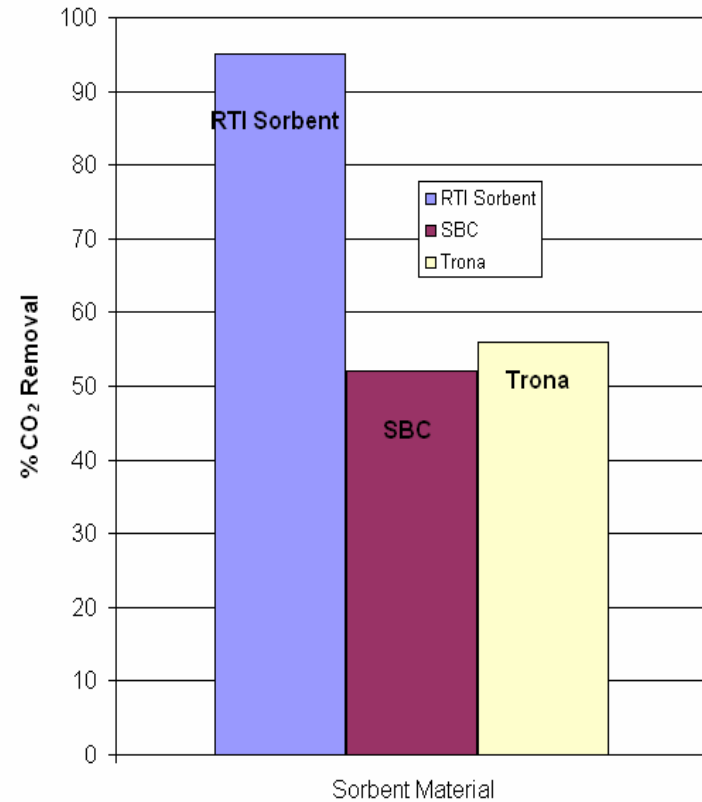


Comparison of Sorbents

Amount CO₂ Removed: Comparison of Sorbents



% CO₂ Removal: Different Sorbents



Summary

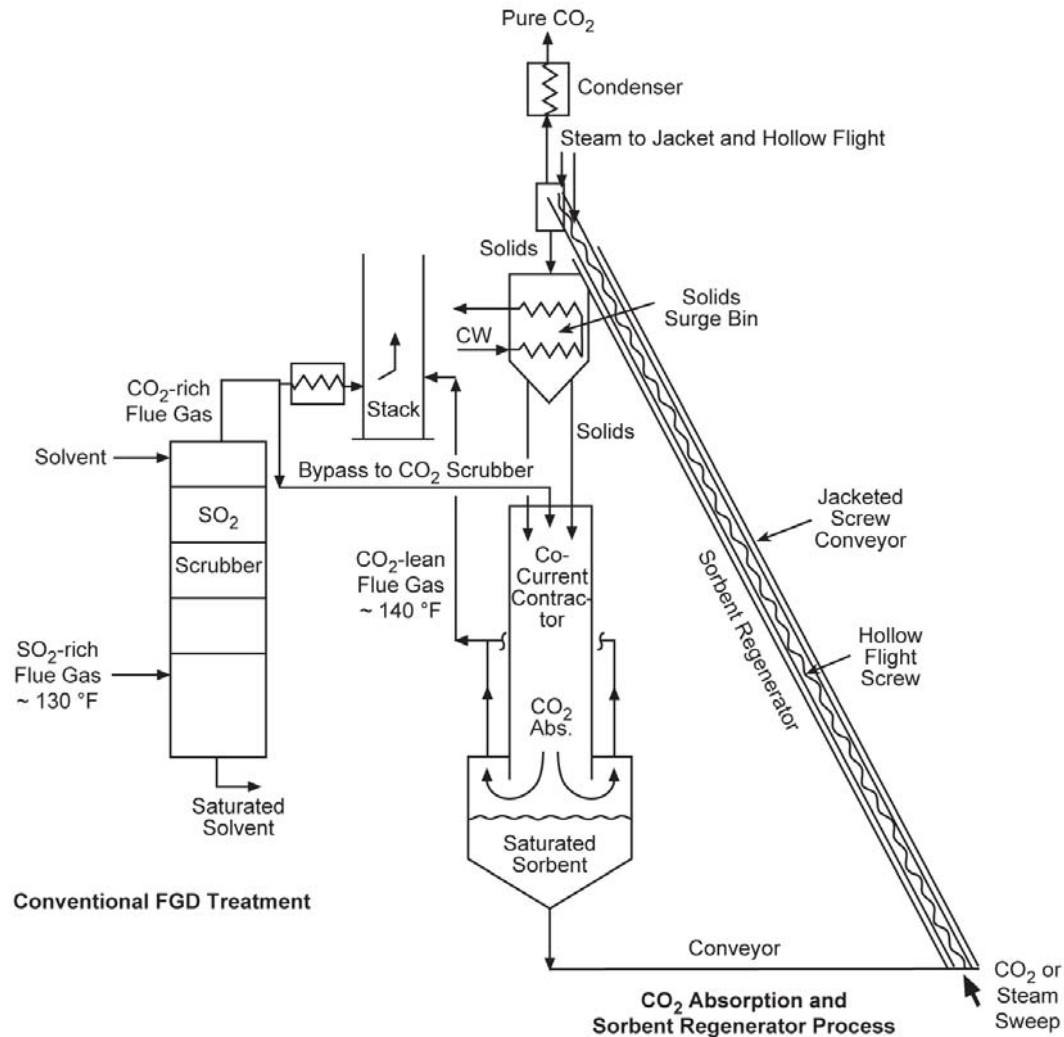
- Developed optimized RTI sorbent – commercially produced by Süd-Chemie, Inc.
- 90% CO₂ removal demonstrated in pilot-scale entrained-bed reactor
- Sorbent reactivity was maintained over 7 cycles (>90%)
- Negligible attrition over 7 cycles
- Amount of CO₂ removal increased and percentage CO₂ removal decreased with higher starting CO₂ concentration
- Supported sorbent removed more CO₂ and a higher percentage of CO₂ than commercial SBC and Trona

Engineering Design Challenges

- Heat integration
 - Capturing low-grade, low-value heat in the steam cycle for sorbent regeneration
 - Minimizing parasitic power consumption
- Low pressure drop of flue gas stream
 - Minimizing additional power requirements of the I.D. fan
- Sorbent Transfer
 - Efficiently move sorbent between carbonation reactor and regenerator

These challenges may be solved using new process design

Conceptual Process



Energy Advantage of Dry Carbonate Process

	Conventional Plant, no CO ₂ Capture	CO ₂ Capture Using Amine Process (MEA)	“Dry Carbonate” Conceptual Process
Flue Gas Flow Rate, lb/hr	4,151,000	4,151,000	4,151,000
CO ₂ Content, lb/hr	789,000	789,000	789,000
CO ₂ Capture, %	--	90%	90%
CO ₂ Captured, ton/yr (@80% capacity factor)	--	2,490,000	2,490,000
Unit Basis, lb steam/lb CO ₂	--	2.29	1.64
Regeneration Steam Flow, lb/hr	--	1,624,000	1,166,000
Regeneration Heat Ratio of Dry Carbonate to MEA		--	72%

The energy needed for regeneration is 72% of the competing amine process

Energy Advantage of Dry Carbonate Process (cont'd)

	Conventional Plant, no CO ₂ Capture	CO ₂ Capture Using Amine Process (MEA)	“Dry Carbonate” Conceptual Process
Gross Plant Power, MWe	491	372	406
Auxiliary Power, MWe	29	73	74
Net Power Output, MWe	462	300	332
Ratio of Dry Carbonate to MEA process			111%

Using carbonate materials for CO₂ capture, 11% additional power could be produced in a coal fired power plants compared to CO₂ scrubbing by an MEA type amine process.

Future Work

- Demonstration of Conceptual Process Design
 - Heat integration
 - Pressure drop minimization
 - Sorbent Transfer
- Flue gas slipstream testing of technology at a power plant site
- Comprehensive technical and economic evaluation with DOE/NETL guidelines
- Technology commercialization

Acknowledgements

- Financial Support from DOE/NETL
 - Cooperative Agreement No. DE-FC26-00NT40923
- Technical Guidance
 - José Figueroa (DOE)
 - Carlos Salvador (CANMET)
 - John Maziuk (Solvay Chemicals)
 - Doug Harrison (LSU)
- Industrial Partnerships
 - Church & Dwight
 - Süd-Chemie, Inc.